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MODELING THE EFFECTS OF HIGH-G STRESS ON PILOTS

IN A TRACKING TASK

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SUMMARY

Air-to-Air tracking experiments have been conducted at the Aerospace Medical Research Laboratories (AMRL) using both fixed and moving base (Dynamic Environment Simulator-DES) simulators. The obtained data, which includes longitudinal error of a simulated air-to-air tracking task as well as other auxiliary variables, was analyzed using an ensemble averaging method.

In conjunction with these experiments, the Optimal Control Model (OCM) is applied to model a human operator under high-G stress.

INTRODUCTION

Recent efforts at Aerospace Medical Research Laboratories, WPAFB, have demonstrated initial feasibilities of applying the Optimal Control Model [1] of human response to the air-to-air tracking problem. The model has been able to generate predictions of ensemble mean and standard deviations of longitudinal tracking error, aircraft state variables and attained G forces corresponding to arbitrary target profiles. The preliminary modeling efforts were focused on two subproblems. First, effects that related cost functional weightings and internal model parameter changes to G-stress were considered. Second, a structural change of the model was suggested. The data for this model development and validation has been generated on the centrifuge (DES) facility at AMRL. The most recent data vs. model comparisons have shown excellent correspondance for tracking error ensemble statistics. Further model refinement efforts are now under investigation.

ENGAGEMENT SCENARIO

Figure 1 shows the geometry of the air-to-air tracking in the longitudinal plane [2]. In our modeling efforts we assumed no gunsight dynamics, i.e. the sight is fixed and aligned with the aircraft body axis. An additional simplification has been added by assuming that pitch angle equals the flight path angle.

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PLANAR ANGLES (LONGITUDINAL)

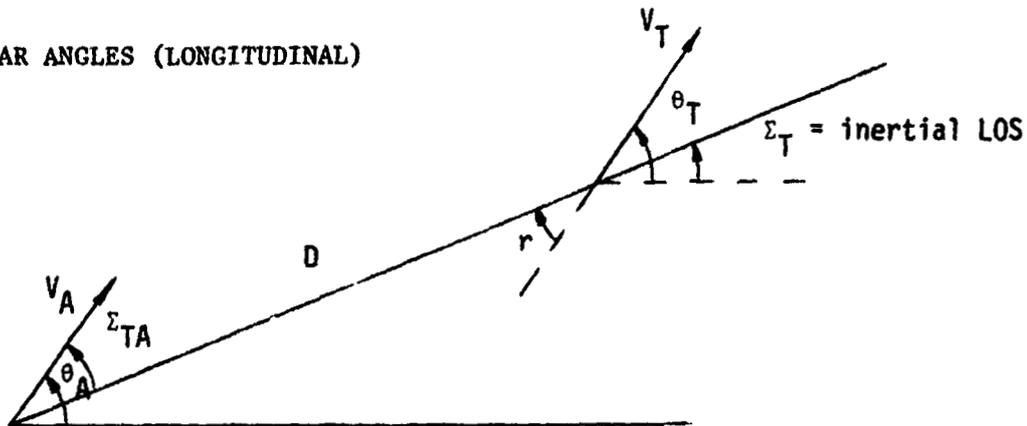


FIG. 1: TRACKING GEOMETRY

θ_A = pursuer fp angle

θ_T = evader fp angle

Σ_T = inertial line of sight

$\Sigma_{TA} = \theta_A - \Sigma_T$ = relative line of sight

$r = \theta_T - \Sigma_T$ = aspect angle

OPTIMAL CONTROL MODEL FOR AIR-TO-AIR TRACKING

The OCM, modified to treat deterministic target motion assumes the system dynamics

$$\dot{\underline{x}}(t) = A_0 \underline{x}(t) + \underline{b}_0 u(t) + F_0 z(t) \quad (1)$$

$$\underline{y}(t) = C_0 \underline{x}(t) \quad (2)$$

where $u(t) \triangleq \delta_A$ is the elevator deflection and $z(t)$ is a function of the target motion. The state vector is

$$\underline{x}' = [q_T, q_A, \alpha_A, \theta_A - \theta_T, e]'$$

where q_T (q_A) is the target (attacker) pitch rate, α_A is the attacker angle of attack and e is the tracking error. The observations are

$$\underline{y}' = [e, \dot{e}, r, \dot{r}]'$$

with correspondance to the OCM assumption on observations. The human perceives only a delayed and noisy signal

$$y_p(t) = y(t-\tau) + v_y(t) \quad (3)$$

where $v_y(t)$ is a white observation noise with covariance

$$v_{y_i}(t) = \frac{\rho_y^\circ}{f_i(t)} \cdot \frac{(\bar{y}_i^2 + \sigma_i^2)}{N^2(a_i)} \quad i = 1, \dots, 4 \quad (4)$$

τ = operator time delay

ρ_y° = nominal noise to signal ratio

$f_i(t)$ = fractional attention allocation to the i -th observed variable

$N(a_i)$ = equivalent gain of the visual/indifference threshold a_i

\bar{y}_i = mean of y_i

σ_i = standard deviation of y_i

The control input corresponds to the differential equation

$$\dot{u}(t) = -L_c \begin{bmatrix} \hat{x}(t) \\ u(t) \end{bmatrix} + \frac{1}{\tau_N} v_u(t) \quad (5)$$

where L_c is the feedback gains vector, $\hat{x}(t)$ is the estimated state, τ_N is the neuro-motor time constant and $v_u(t)$ is a white motor noise with covariance proportional to the covariance of $u(t)$

$$V_u(t) = \rho_u \text{cov}[u(t)], \quad (6)$$

ρ_u being the motor noise ratio coefficient. The system matrices are

$$A_o = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & M_q & M_a & 0 & 0 \\ 0 & 1 & Z_a & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & V/D & 0 \end{bmatrix} \quad b_o = \begin{bmatrix} 0 \\ M_\delta \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$C_o = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & V/D & 0 \\ 0 & 0 & 0 & -1 & 1 \\ 1 & 0 & 0 & V/D & 0 \end{bmatrix}$$

The vertical accelerations of the target, and those commanded by the attacker are respectively

$$G_T(t) = \frac{V}{g} \cdot x_1(t) + 1 \quad (7a)$$

$$G_A(t) = \frac{V}{g} \cdot x_2(t) + 1 \quad (7b)$$

The constants are

$$M_\delta = 11$$

$$V = 1000 \text{ ft/sec} \quad D = 1000 \text{ ft.}$$

$$g = 32.2 \text{ ft/sec}^2$$

$$M_q = -7.63 \text{ sec}^{-1}$$

$$M_\alpha = -20.66 \text{ sec}^{-1}$$

$$Z_\alpha = -2.27 \text{ sec}^{-1}$$

A typical G_T time history, used in the present AMRL studies is shown in Fig. 2.

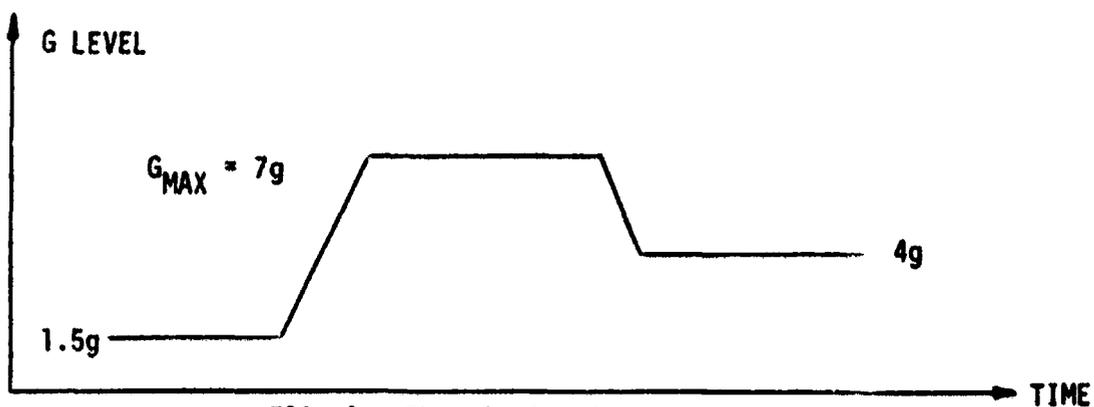


FIG. 2: TYPICAL G_T TIME-HISTORY

The internal model parameters were set to their nominal values $\tau = .2$ sec, $\rho_u = -20$ dB, $\rho_y = -14$ dB, $\tau_N = .1$ sec. Usually, the nominal value of ρ_y ($=\rho^0$) for a single observation channel would be -20 dB. In our case there are 4 observation channels which increase the nominal ρ_y to -14 dB.

PILOT MODEL REVISION AND RESULTS

Motivated by recent results in modeling AAA tracking under high uncertainty [3], we write the human's internal characterization of target motion ($x_1 = q_T$) as

$$\dot{x}_1(t) = -\alpha(t) x_1(t) + z_1(t) \quad (8)$$

rather than

$$\dot{x}_1(t) = z(t). \quad (9)$$

Now,

$$z_1(t) = z(t) + \alpha(t) x_1(t) = \frac{R}{V} [\dot{G}_T(t) + \alpha(t) G_T(t)] \quad (10)$$

Using this approach we note the following facts:

1. $\alpha(t)$ does not affect the system model.
2. $\alpha(t)$ does affect the Kalman filter submodel equation associated with this state,

$$\dot{x}_1(t) = -\alpha(t) x_1(t) + \xi(t); \quad \xi(t) - \text{white noise} \quad (11)$$

The target motion is perceived by the human operator as a Markov process as opposed to a random walk ($\alpha=0$). It reflects the pursuer's uncertainty in perceiving the target's motion. $\alpha(t)$ is chosen according to

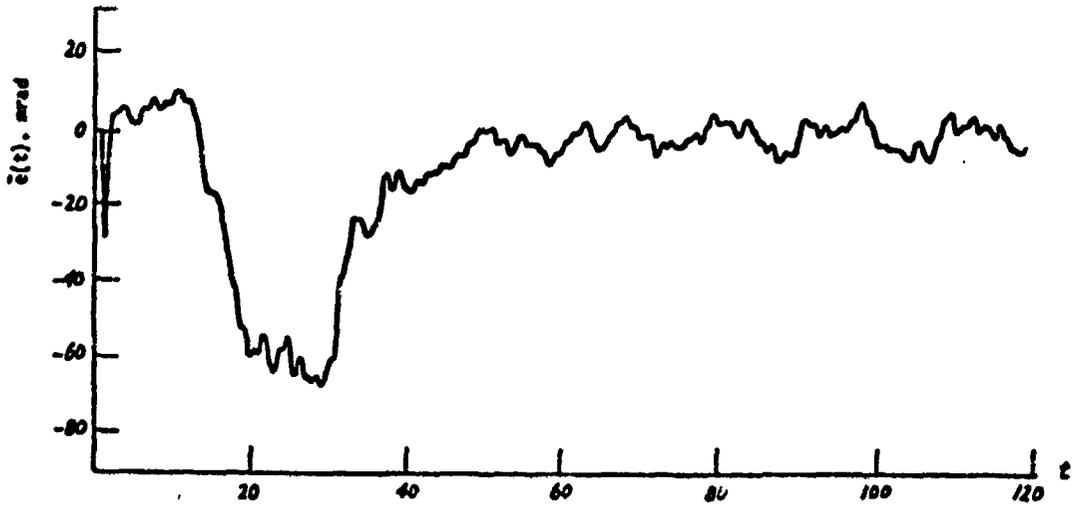
$$\tau_L \dot{\alpha}(t) + \alpha(t) = \mathcal{N}(G_T) \cdot \sqrt{\Sigma_{11}} \quad (12)$$

where

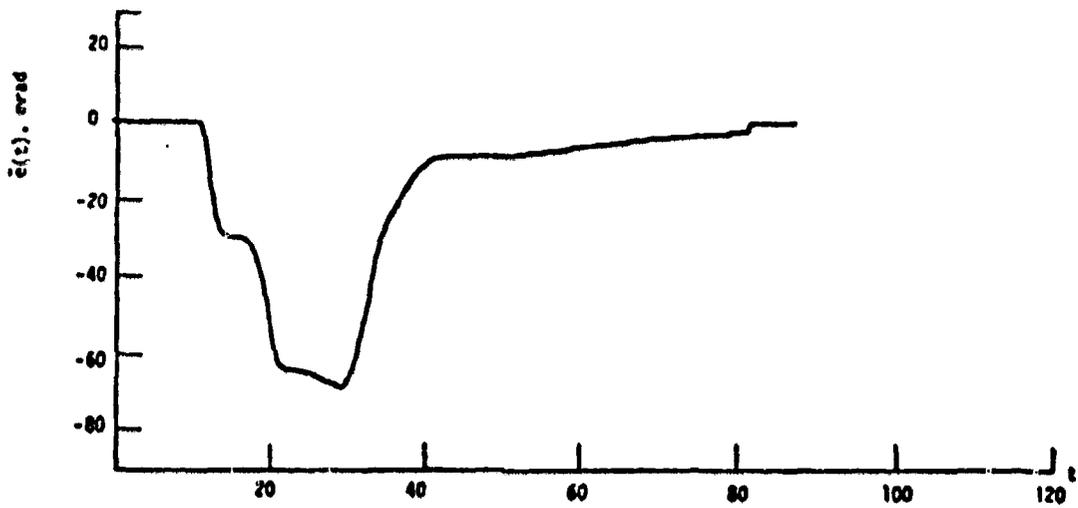
$$\mathcal{N}(G_T) = 3 \cdot \left(\frac{G_T}{4}\right)^4 \quad (13)$$

The resulting model-vs-data comparisons for ensemble mean error ($\bar{e}(t)$) for dynamic and static-G cases (G-stress and no G-stress) are shown in Figures 3-4, respectively. The agreements are excellent through the transient G peak to recovery. Nominal parameters have been used for the basic OCM response parameters; the only change between static and dynamic cases is

$$\tau_L = \begin{cases} .53 & \text{static} \\ .97 & \text{dynamic} \end{cases} \quad (14)$$

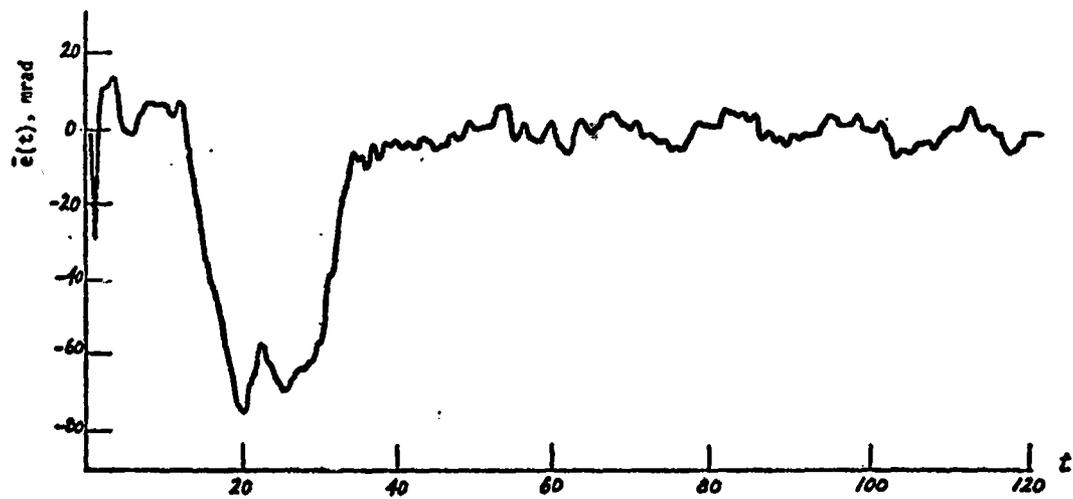


a) Experimental Data

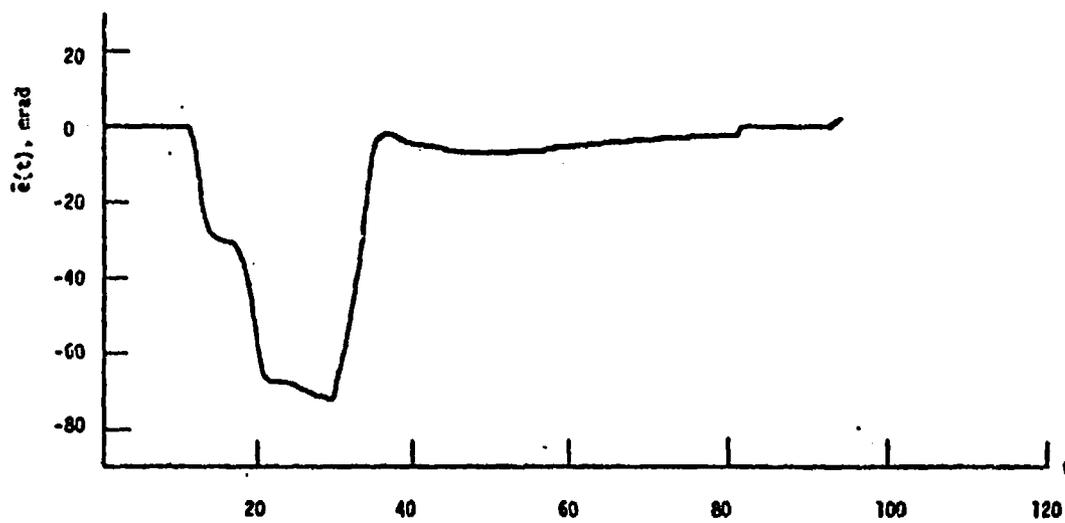


b) Model Predictions

FIG. 3: MEAN PITCH TRACKING ERROR, 1 PEAK, G STRESS



a) Experimental Data



b) Model Predictions

FIG. 4: MEAN PITCH TRACKING ERROR, 1 PEAK, STATIC G

CONCLUDING REMARKS

A preliminary modeling work in the area of air-to-air tracking task has been conducted and the initial results have been extremely encouraging. However, further research is needed, and is presently continuing, to interpret these results and to match the standard deviation data.

For modeling work, a major concern is involved with the OCM internal parameters and their dependence on G_z and \dot{G}_z levels. A set of new experiments will be conducted in the near future to enhance the observations of this dependence.

Also, the present model formulation does not include any motion-derived cues as G_z or \dot{G}_z ; it merely regards these quantities as external stressors, and neglects any useful motion cues that they may provide. It is the feeling of the authors that this aspect of modeling work need to be considered in any future modeling efforts.

REFERENCES

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2. Harvey, T.R. and Dillow, J.D.: Application of an Optimal Control Pilot Model to Air-to-Air Combat. AIAA Guidance and Control Conference, August 1974.
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